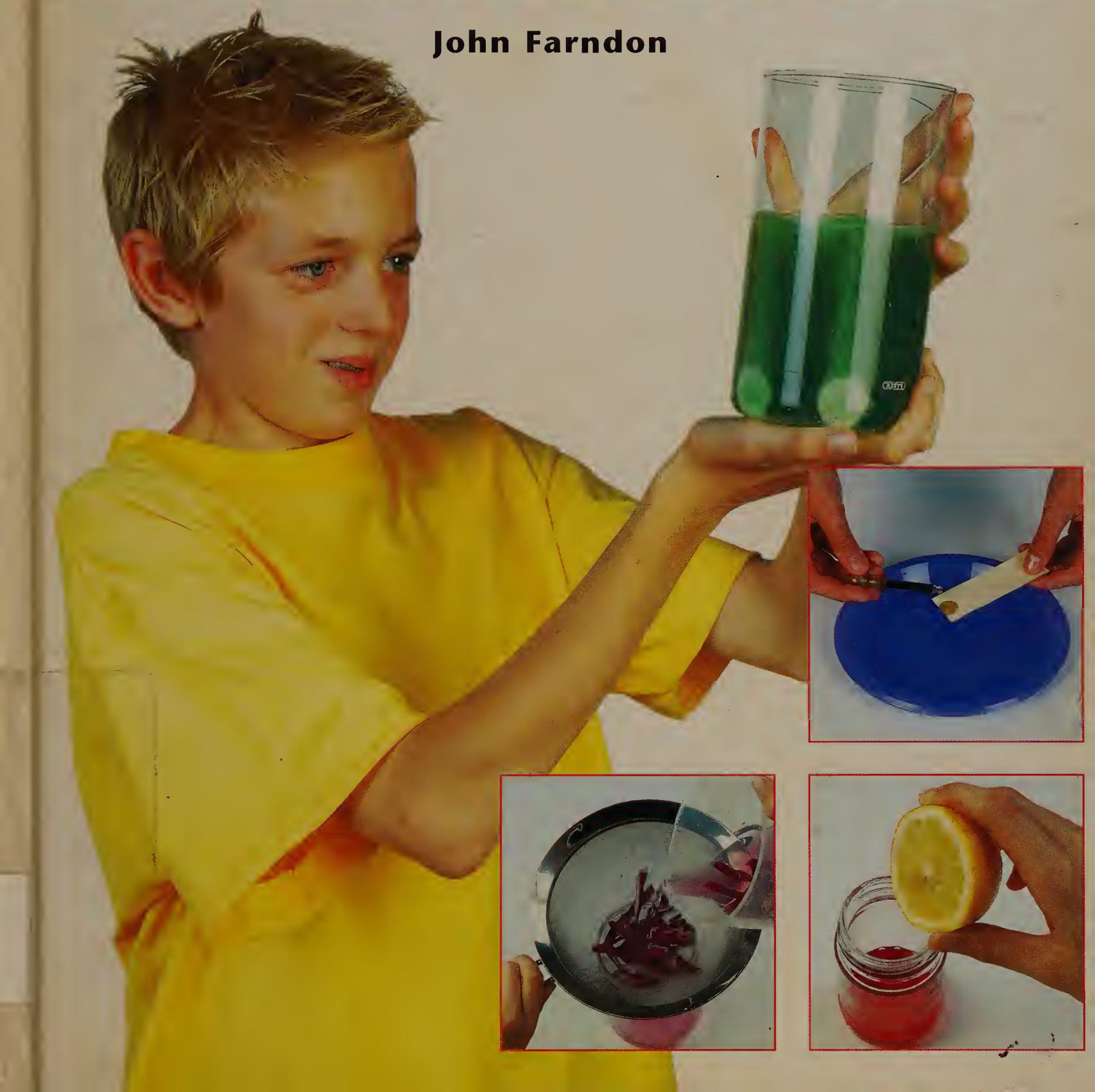
Science Experiments

CHEMICALS

John Farndon



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Science Experiments

CHEMICALS

by
John Farndon

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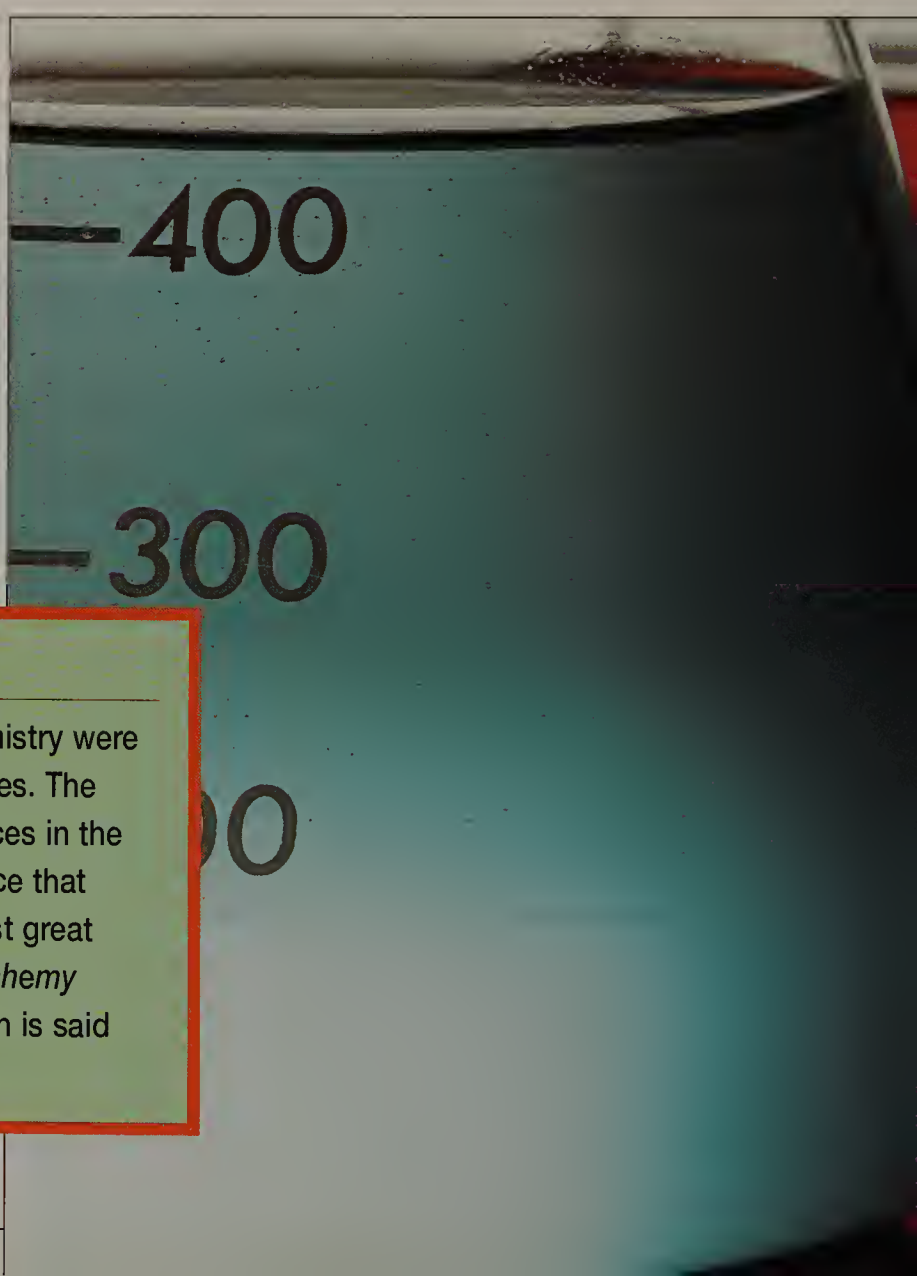
WHAT ARE CHEMICALS?

The word "chemicals" makes people think of laboratories full of steaming jars and dangerous liquids. In fact, chemicals are not just weird substances that scientists play with. Every substance on Earth and in the whole universe is made from chemicals, from plain tap water to exotic metals deep underground. Indeed, your body and every other living thing is made entirely of chemicals. Even the air around us is made from a combination of chemicals.

Just as a cake is made up from different ingredients, everything is made from combinations of chemicals. Some substances, like table salt, are made up of just one main chemical, while others, like human skin, are made from many. The same chemicals can be found in many different substances. It is the special combination of chemicals that makes each substance the way it is.



Most chemicals are everyday substances. Only a few are strange-looking fluids in laboratory flasks like these.

Did you know?

The foundations of the science of chemistry were laid by the alchemists of the Middle Ages. The alchemists brewed and mixed substances in the vain hope of finding a magical substance that would turn iron to gold. Many of the first great alchemists were Arab, and the word *alchemy* comes from the Arabic *al quemia*, which is said to mean the art of pouring.

In focus

PHYSICAL PROPERTIES

These are some of the physical properties that chemicals can have:

- State: Is it a solid, a liquid, or a gas? At what temperature does it boil, freeze, or melt?
- Appearance: What color is it? Is it shiny or dull? Is it clear or opaque?
- Texture and shape: Is it a powder or a crystal? Is it rough or smooth to the touch? Is it oily or watery?
- Plasticity: Does it bend, stretch, or squash easily?
- Elasticity: Does it spring back to its original shape after bending, stretching, or squashing?
- Toughness: How hard is it? Does it break easily?
- Density: How heavy is it?
- Buoyancy: Does it float?
- Heat properties: Is it cold to the touch? Does it heat up or cool down quickly?

Glass is easy to identify by its physical properties. It is hard and clear, but also very brittle and shatters easily.

Each chemical has its own properties and a scientific name. Salt, for example, is made of the chemical called sodium chloride. Some properties are simply physical—what the chemical looks like, how it feels to the touch, how it reacts to being bent, hit, pulled, and so on. "Chemical" properties are how a chemical reacts with another chemical. Baking powder and talcum powder are both fine, white powders, so are physically similar. Yet they are chemically different because baking powder reacts with vinegar to create a froth; talcum powder does not react at all.

ELEMENTS AND COMPOUNDS

Gold is highly resistant to corrosion, which is why it nearly always shines. This is also why it is one of the very few elements to occur naturally in pure form. Gold atoms have 79 protons each.

There are billions of different substances in the universe. Yet, remarkably, all these different substances are made from few more than 100 basic chemicals called elements. Iron, oxygen, and hydrogen are all examples of elements.

Every substance can be broken down into increasingly simple chemicals until it is separated into the elements it is made from. Elements are the simplest possible substances, and cannot normally be broken down any further. It takes extreme conditions like the incredibly hot core of a star to break elements down.

Ninety-two elements are known to occur naturally. But scientists have created more than 30 in the laboratory, such as the strangely named ununhexium and ununoctium, and also seaborgium, named after scientist Glenn Seaborg. Many of these laboratory-created elements sometimes flash into existence for no more than a fraction of a second.

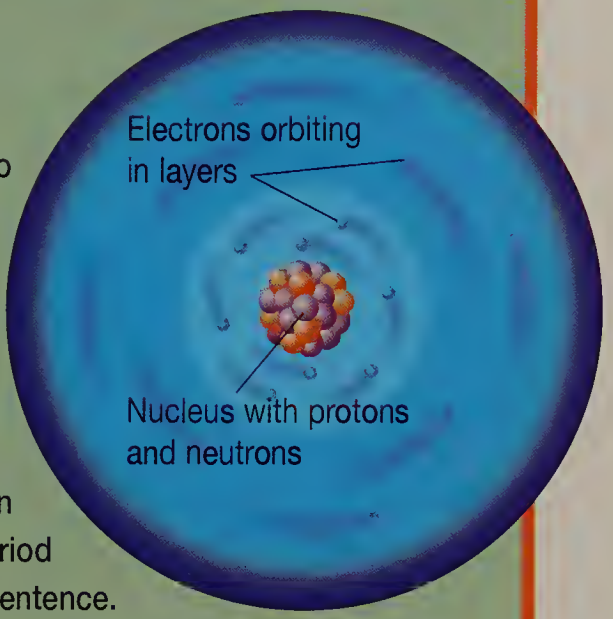
Some substances, such as gold, are made from just one element. If they occur naturally, they are called native elements. Others contain two or more elements joined together and are called compounds. Table salt, for example, is a compound of two elements, sodium and chlorine, which is why it has the chemical name sodium chloride.

Surprisingly, compounds have completely different properties to the elements that make them up. Sodium is actually a soft metal that burns and spits when put in water. Chlorine is a thick, poisonous, green gas.

In focus

ATOMS

Every element and compound—and so every substance in the universe—is made up from incredibly tiny particles called atoms. Atoms are so small, two billion would fit on the period at the end of this sentence. Atoms are mostly empty space dotted with even tinier particles. In the center is the nucleus or core, made from two kinds of particle—protons and neutrons. Around the nucleus are the smallest particles of all, electrons. Each atom usually has an equal number of protons and electrons, and the way an atom behaves depends on just how many there are. Each of the different elements is made from atoms with a certain number of protons. Hydrogen atoms are the smallest of all atoms, with just a single proton. Iron atoms have 26 protons. Uranium atoms have 92, the most that occur naturally in an atom.

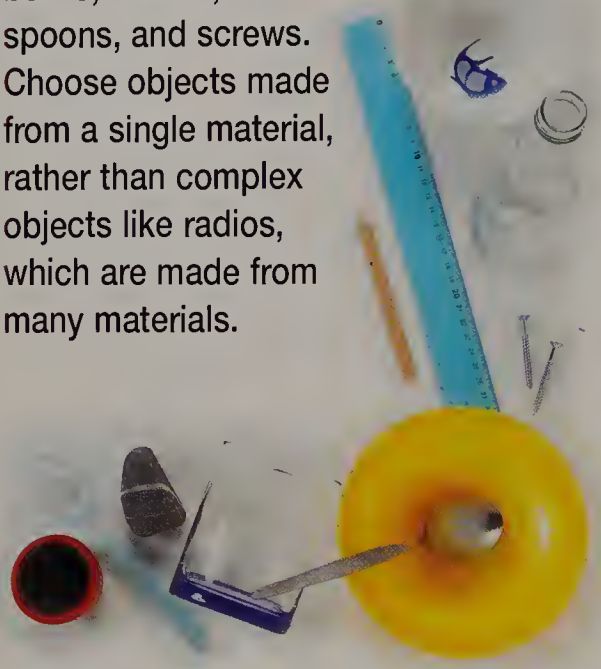


This is an artwork of an atom, showing the nucleus (core) with layers of electrons orbiting around it.

CHEMICALS AT HOME

You will need

✓ Household items such as bowls, bottles, spoons, and screws. Choose objects made from a single material, rather than complex objects like radios, which are made from many materials.

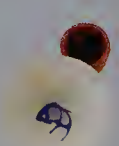


1 Start by separating out metals, which are often shiny, hard, and feel cold. Stone is also cold and hard but not usually shiny.

Material groups

This is one way you can group household materials, with some of the properties you can use to identify them and the chemicals they are made from.

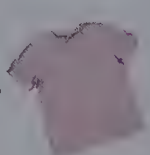
METALS like iron and copper are:
often shiny, strong, hard, dense, bendable, conduct heat and electricity well, may react with air, water, and acids.
Chemical: Metal elements



CERAMICS like china and bricks are:
hard, strong in some directions, brittle, heat resistant, chemically unreactive.
Chemical: Silicon, oxygen, aluminium, hydrogen

PLASTICS like PVC vary but most are:
flexible, easily melted and molded, may burn when heated in air
Chemical: Carbon, hydrogen, various nonmetals

GLASSES are:
like ceramics, but transparent
Chemical: Silicon, oxygen, various metal elements



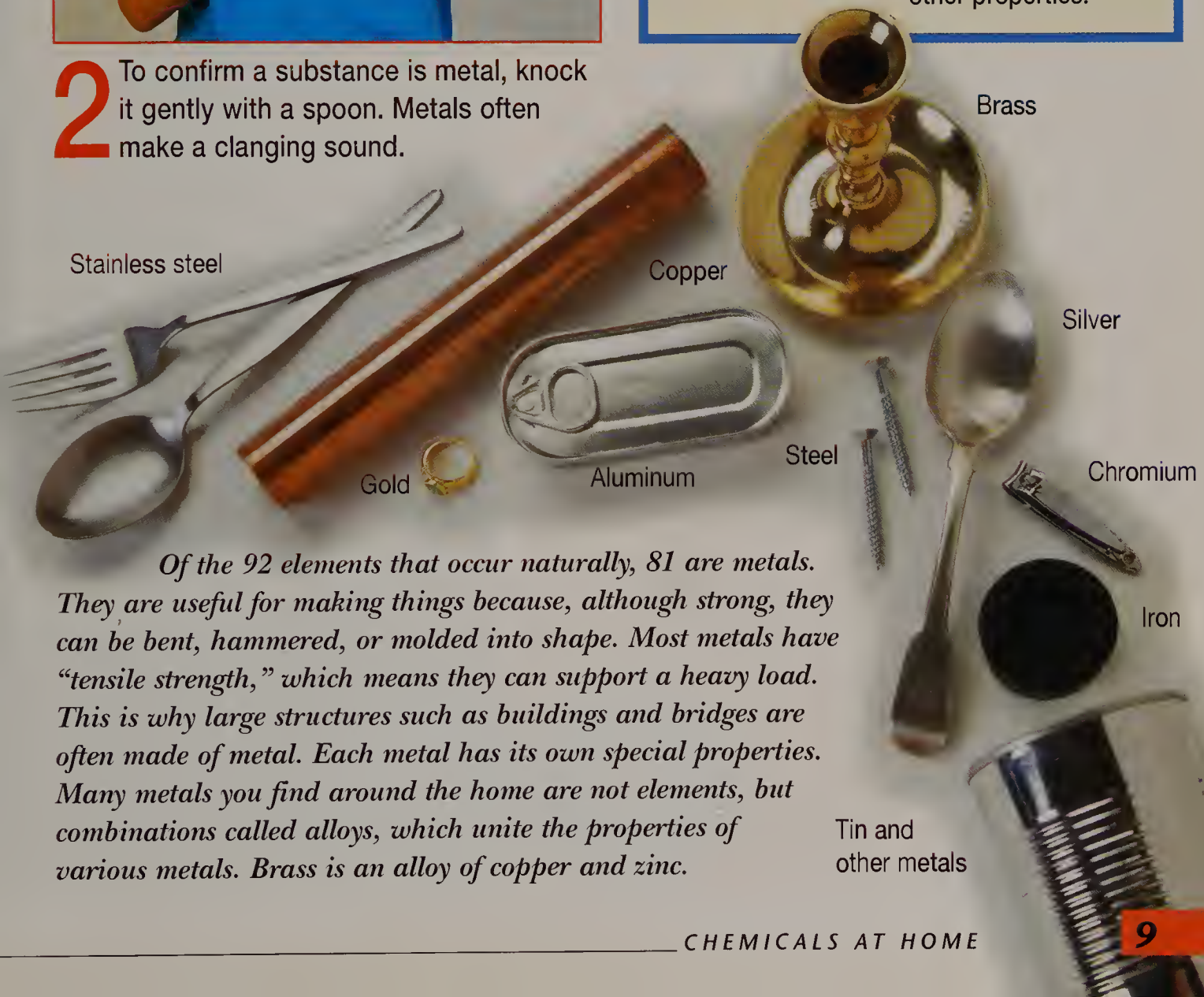
FIBERS are:
flexible, burn when heated in air, form long hair-like strands
Chemical: Carbon, hydrogen, various nonmetals

NATURAL MATERIALS such as wood and stone:
vary greatly
Chemical: Most elements (wood is carbon and hydrogen)

2 To confirm a substance is metal, knock it gently with a spoon. Metals often make a clanging sound.

Take it further

Once you have separated out the metal objects, see if you can separate out all the other objects made from a single material and find ways of grouping them. Decide, for instance, if the material is natural, like wood, or human-made, like glass and plastics. Then try grouping the human-made materials into ceramics, plastics, glasses, and fibers. The panel below left lists some of the properties for each group of materials. See if you can identify any other properties.



Of the 92 elements that occur naturally, 81 are metals. They are useful for making things because, although strong, they can be bent, hammered, or molded into shape. Most metals have "tensile strength," which means they can support a heavy load. This is why large structures such as buildings and bridges are often made of metal. Each metal has its own special properties. Many metals you find around the home are not elements, but combinations called alloys, which unite the properties of various metals. Brass is an alloy of copper and zinc.

CHEMICALS TOGETHER

The atoms of some elements, like helium, exist on their own. But most join up with each other. When atoms link together, they form a new particle called a molecule.

Molecules are the smallest parts of a chemical to exist alone. Some are single atoms, but most are combinations. Atoms of hydrogen, for instance, usually pair up. Hydrogen gas is really hydrogen molecules, made from pairs of atoms.

When atoms of one element join atoms of another, they form

The water we rely on for so many things is a compound of hydrogen and oxygen. In every molecule of water, two hydrogen atoms combine with one oxygen atom.

In focus

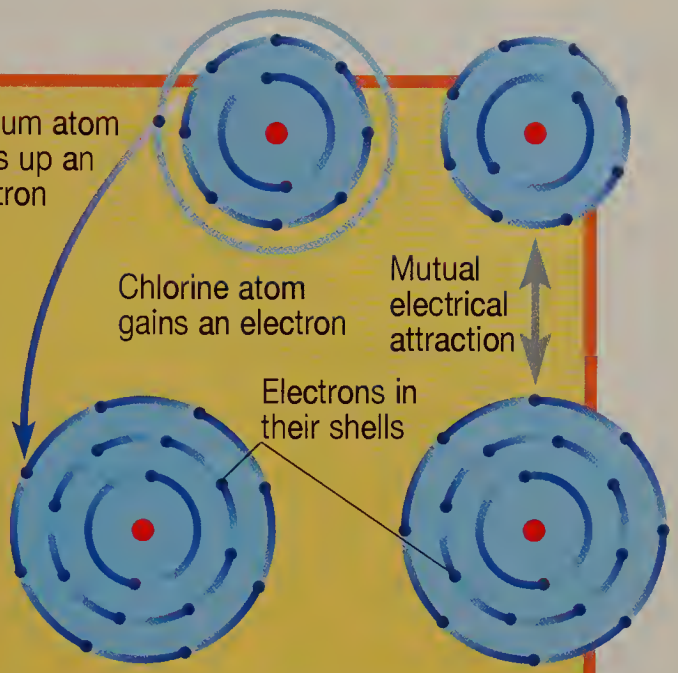
COVALENT BONDS

Nonmetal atoms have too few electrons for a full outer shell. But they can get a full set by sharing pairs with each other. The shared electrons are pulled equally by electrical attraction towards the nuclei of each atom, so the atoms bind together with their electron shells overlapping. Electron-sharing bonds like this are called covalent. A carbon atom can bond like this with four atoms at once, which is why it can make many compounds.

In focus

IONIC BONDS

Most metal atoms have just one or two electrons in their outer shell. They can get a full shell by giving these "spares" away. Many nonmetal atoms have too few electrons, so readily capture the metal's spares. Electrons have a negative electrical charge. Losing them gives the metal atom a positive charge; gaining them gives the nonmetal a negative charge. The two oppositely charged atoms are drawn together by electrical attraction, like opposite magnetic poles. Charged atoms are called ions, so this is an ionic bond. Unlike covalent bonds, the attraction is between whole atoms, not just electrons.


Sodium atom gives up an electron
Chlorine atom gains an electron
Mutual electrical attraction
Electrons in their shells

Sodium atoms have one "spare" electron; chlorine atoms have one "missing." So when they meet, the sodium atom donates an electron to the chlorine. The atoms bond to make a molecule of sodium chloride (table salt) by mutual electrical attraction.

a compound. Compounds are never individual atoms, but identical molecules.

Some molecules are simple. Water is one atom of oxygen and two of hydrogen. Others are much bigger. Plastics have giant molecules, built from long chains of atoms.

An atom's readiness to link up to form molecules—and its whole chemical behavior—depends on its electron set-up. An atom's electrons sit in onion-like layers or "shells." For reasons scientists only barely understand, an atom likes to have a "full" outer shell, with the right number of electrons.

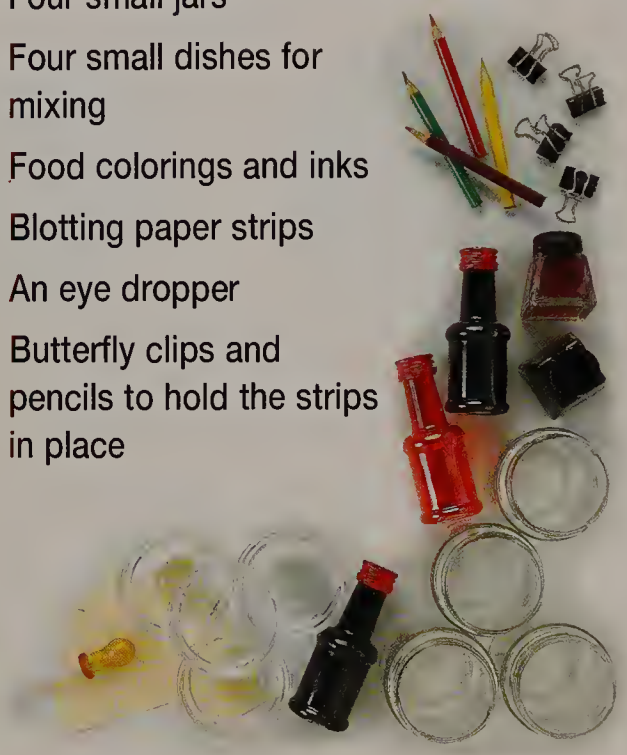
Atoms like helium that do have full shells are chemically slow to react and rarely form molecules. But most atoms have too many or too few electrons and readily form molecules. When they meet other atoms, they lose, capture, or share electrons to get a full set—that is, they react chemically. It is these interactions that bind atoms into molecules.

There are two main kinds of bond: ionic and covalent (see boxes). When different atoms meet and bond, they form a compound. But different atoms can meet and not interact. This is called a mixture.

MIXTURES

You will need

- ✔ Four small jars
- ✔ Four small dishes for mixing
- ✔ Food colorings and inks
- ✔ Blotting paper strips
- ✔ An eye dropper
- ✔ Butterfly clips and pencils to hold the strips in place



1 Pour small quantities of different food colors and inks into each dish to make four different mixtures of colors.

In focus

A mixture of sand and iron powder can be separated by using a magnet to draw out the iron.

MIXTURES

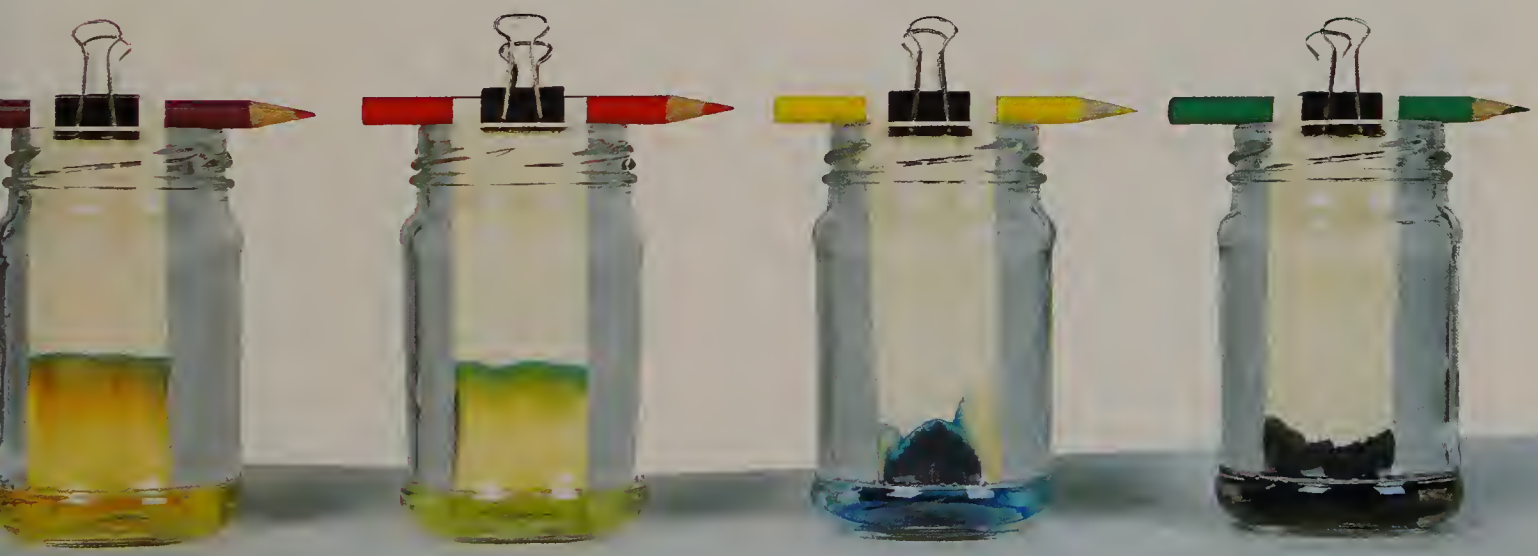
A few everyday substances are made of just one chemical element or compound, such as table salt (sodium chloride). But most are mixtures of several. Food, gasoline, and even air are mixtures. The various chemicals in a mixture may be so thoroughly mixed that it looks like one substance. But they do not react together and, like different marbles in a bag, their molecules remain intact. This means the properties of a mixture are really a combination of those of the different ingredients. So a mix of sugar and water is both sweet and wet. Also, with the right technique, the chemicals in a mixture can be separated out. The chromatography in the experiment is just one of many techniques for separating mixtures.

2 Using a dropper, put a tiny drop of each mixture on the end of each strip of blotting paper.

What is happening?

As the water soaks up through the paper, it carries with it the dyes in the inks and food colors. Some dyes don't dissolve well, so are left on the paper low down. Others dissolve better and are carried farther up. So each dye is left at a different level. This technique for splitting colors is called "chromatography." Forensic scientists use a similar technique to help identify inks and dyes at a crime scene. Hospitals also use it to find if there is sugar in a patient's urine, which would show if he or she had diabetes. Paper is most commonly used for chromatography, but other absorbent materials such as chalk can also be used.

Pour a small amount of water in each jar, then suspend each strip of paper from clips on pencils. Make sure the color drop just dips into the water. Leave for 10 minutes, and you should see how the water carries the inks up through the paper and separates them into the different colors.

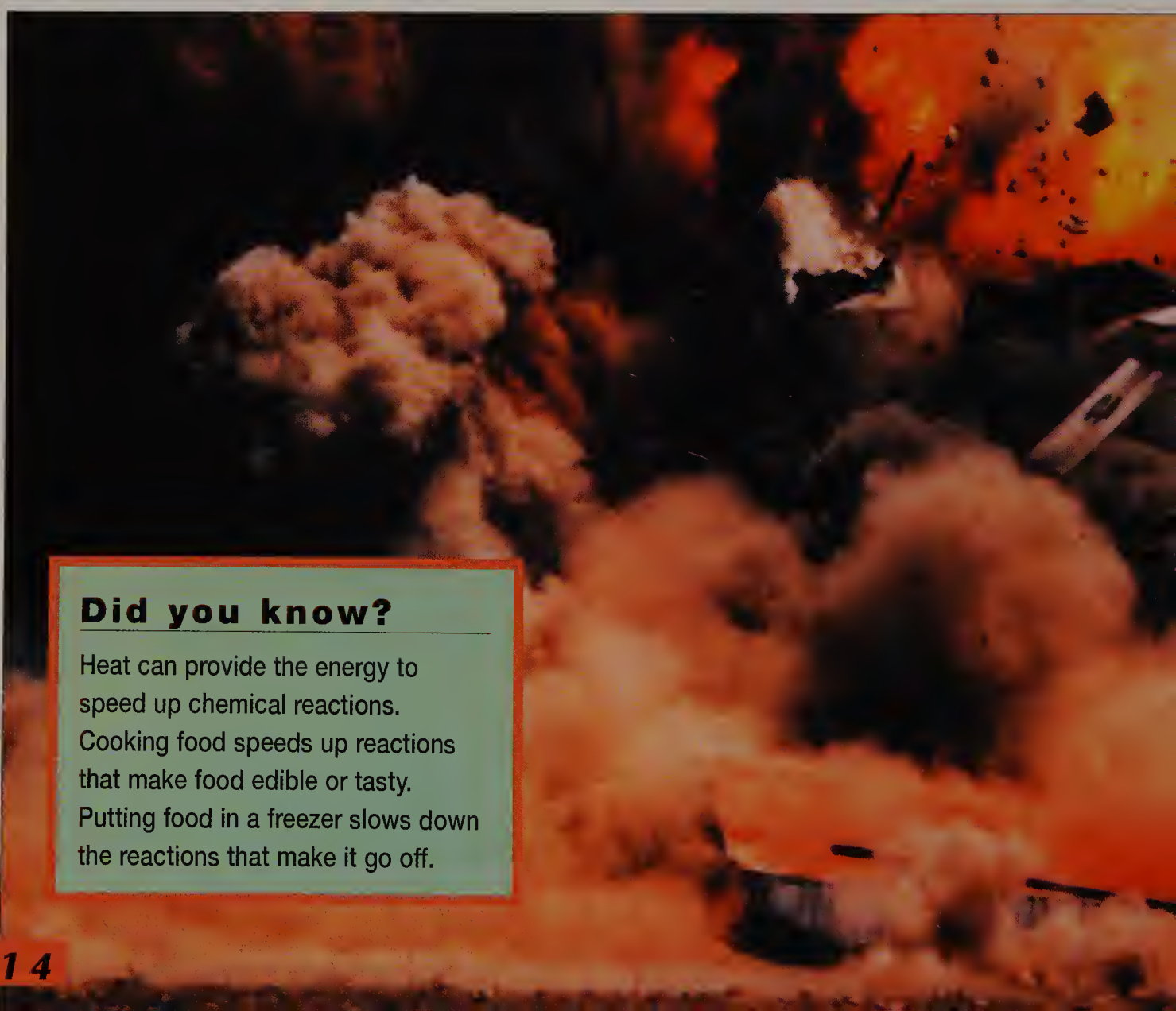


CHEMICAL REACTIONS

Reactions can be so vigorous and make so much heat they make the air expand rapidly. This is an explosion.

Whenever a fire burns, bread rises in an oven, or a nail becomes rusty, a chemical reaction is taking place. In the fire, the chemicals are reacting very quickly. With the nail rusting, they are reacting slowly. But each process involves elements and compounds reacting with each other, and changing in some way.

Chemical reactions are taking place everywhere all the time. All life processes depend on chemical reactions. So too do many household and industrial



Did you know?

Heat can provide the energy to speed up chemical reactions. Cooking food speeds up reactions that make food edible or tasty. Putting food in a freezer slows down the reactions that make it go off.

processes, from the hardening of cement to the creation of new plastics.

There are many kinds of chemical reactions. Some involve just two elements or compounds reacting with each other. Others involve many more. But whenever there is a reaction, at least one of the chemicals is changed, often irreversibly, and new compounds are formed. Some bonds holding molecules together are broken and some new ones are forged.

In the real world

LIFE PROCESSES

As these kittens grow, every new bit of their bodies will be created by chemical reactions inside each body cell.

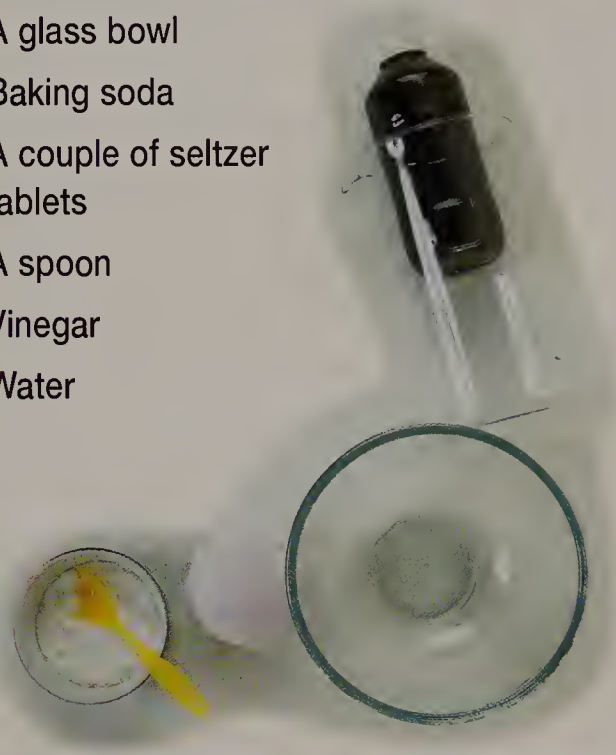
All life depends on chemical reactions. Indeed, it might be true to say that much of life is chemical reactions. Part of the process of food digestion, for example, is a reaction between the chemicals the food is made of and body chemicals such as stomach acid. In fact, every movement of the body involves a chemical reaction, since muscles get their energy from the reaction of sugars with oxygen inside muscle cells. Plants grow because of a series of chemical reactions stimulated by sunlight in photosynthesis. In this, carbon dioxide from the air is joined to hydrogen from water to make the sugars plants use for food.

When substances just mix, they remain intact and can be separated, but when chemicals react, they really change. In fact, the formation of a new compound or the separation of a compound into its separate elements proves a reaction has taken place. Scientists usually call the original chemicals the "reactants" and the new ones formed the "products."

SIMPLE REACTIONS

You will need

- ✔ A large glass container
- ✔ A glass bowl
- ✔ Baking soda
- ✔ A couple of seltzer tablets
- ✔ A spoon
- ✔ Vinegar
- ✔ Water



1 Pour a little vinegar into a bowl—about an egg-cup full. Then take a teaspoon of baking soda.

In the real world

Bread rises as it is baked in the oven because it is full of expanding bubbles of carbon dioxide gas.

RAISING BREAD

One way to make bread rise and become light and fluffy is to add yeast to the dough. Yeast turns sugar in the bread to bubbles of carbon dioxide gas, which swell the bread. Another is to add baking soda and cream of tartar powder to the mix. Cream of tartar is an acid and reacts with the soda in the damp mixture, again creating bubbles of carbon dioxide in the same way as the vinegar in the experiment. Baking powder is soda with acid powder and cornstarch. The soda and acid are kept separate by the cornstarch when dry and only really react when wet.

2 Sprinkle the baking soda quickly into the vinegar and see how it instantly foams and makes a smell.

What is happening?

In the experiments with vinegar and the seltzer tablet, the fizz is a chemical reaction called "effervescence." In this, an acid dissolved in water reacts with a "base" (non-acid) to form tiny bubbles of gas (usually carbon dioxide). Vinegar is weak acetic acid and reacts strongly with the soda, which is a base, chemically known as sodium hydrogencarbonate. The seltzer tablet contains a basic salt such as magnesium sulfate, but also citric acid. While dry, the salts and acid in the tablet do not react, but as soon as they get wet, they dissolve in the water and react together to produce bubbles of carbon dioxide gas.

Some stomach-settling products are designed to react with water. Seltzer tablets and liver salts fizz when they come into contact with water. Try dipping a seltzer tablet slowly into a jar of water and watch what happens. See if you can spot how some bits sink to the bottom as the tablet dissolves. Look, too, for the gas bubbles produced as each grain hits the water. The grains make the water fizz. The green in the water here is food color added for effect.

BURNING AND RUSTING

Oxygen, with nitrogen, is one of the two main gases in the air. It is also a highly reactive chemical, and a huge number of everyday processes are chemical reactions involving oxygen. Fires burning, metals rusting, and even breathing all involve oxygen reactions.

When oxygen reacts with a substance, it links up with the substance to form a new compound. The substance is said to be oxidized, and the process is called "oxidation." When this happens, atoms of the oxidized substance always lose either electrons, the gas hydrogen, or both. So scientists say oxidation is any reaction in which atoms lose electrons or hydrogen—whether oxygen is involved or not.

Just as a substance can gain oxygen, it can also lose it. A substance losing its oxygen is said to be reduced. In fact, reduction always occurs at the same time as oxidation—when one substance gains oxygen,

In focus

Providing there is moisture in the air, steel quickly rusts as it is oxidized.

RUSTING

Iron and steel can quickly turn rusty if exposed to oxygen in the air. The oxygen destroys the iron by combining with it and turning it to iron oxide. But rust only really develops if there is moisture. Rust is not just iron oxide, but a special kind called "hydrated" iron oxide, which forms when iron oxide reacts with water. Once a surface starts to rust, it turns brittle, swells up, and flakes off. This exposes the surface to more air and water, and so rusting continues. The presence of impurities like salt accelerates the process.

Did you know?

There is no oxygen in space, so some spacecraft have a tank of liquid oxygen to enable the rocket fuel to burn.

another must give it up. Combined reduction and oxidation reactions are often known as redox reactions.

The most spectacular redox is burning, known by scientists as combustion. Burning usually involves a reaction between oxygen in the air and a fuel, which is the substance burned—whether it is coal, wood, gasoline, or even rubbish on a bonfire. But only gases combine readily with oxygen. If the fuel is solid or liquid, it must first get hot enough to vaporize—that is, change to a gas.

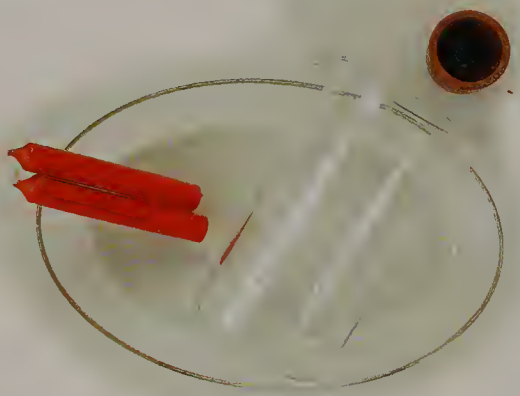
Each fuel has its own ignition point—the temperature at which it gives off enough gas to burn. Gasoline has a very low ignition point, and even a small spark is enough to make it burst explosively into flame. Wood has a much higher ignition point and may not catch fire even after sustained efforts with a match. Many substances won't burn at all at any temperature.

Fire is a violent chemical reaction, usually between oxygen and a fuel, that produces heat and light.

FIRE AND OXYGEN

You will need

- ✔ A large glass dish
- ✔ A small candle holder (or egg cup)
- ✔ A pitcher
- ✔ A tall glass container
- ✔ Candles



1 Cut a candle in half and set it in a small holder in the center of a dish. Pour in plain tap water to half fill the dish.

2 Light the candle. Let it burn for a few minutes until the flame is steady. **Always take care with naked flames.**

3 Carefully lower the jar over the flame at a slight angle and stand it on the base of the dish. Note the water level in the jar.

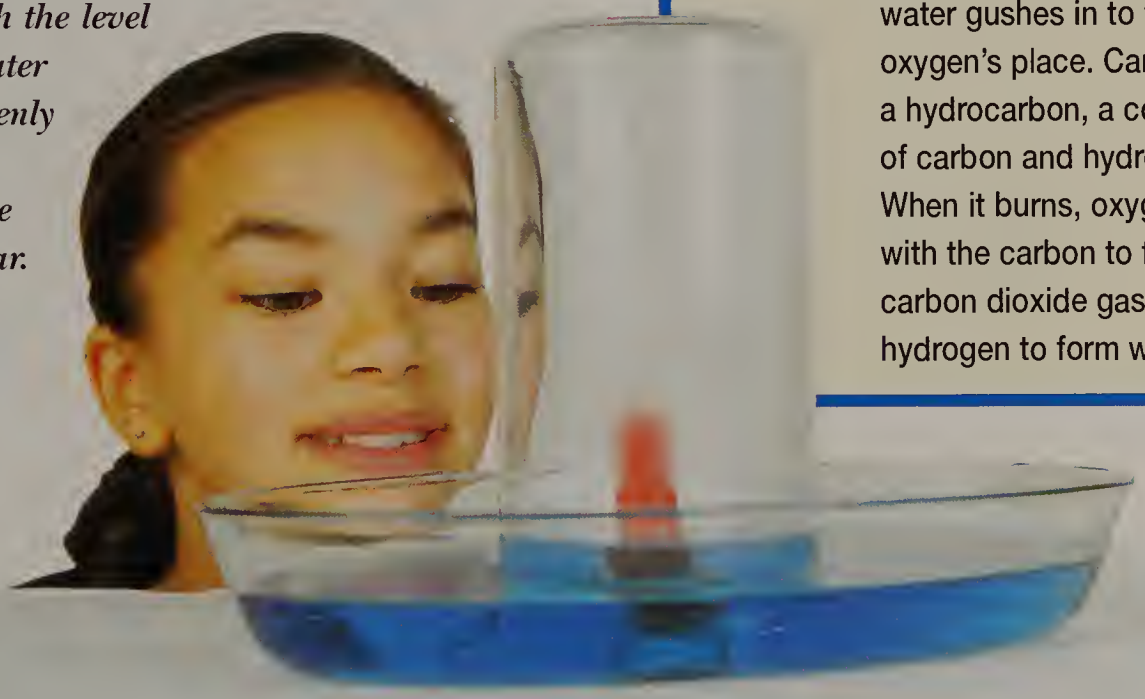
In the real world

Cream fire extinguishers mix cooling water with carbon dioxide foam to smother a fire.

FIRE EXTINGUISHERS

Each kind of fire needs its own extinguisher, so canisters are color-coded. Red ones work by covering the fire with a spray of cooling water, since things only burn if hot enough. Black ones hold dense carbon dioxide gas which sinks over the fire and smothers it—so keeping out the air and depriving it of the oxygen it needs. Blue extinguishers blow out soda powder, which also settles over the fire and prevents air from reaching it.

If the flame is snuffed out instantly, take off the jar, relight the candle and try again after leaving it to burn down a little. The candle should burn inside the jar for several seconds, before finally sputtering out. As the flame dies out, watch the level of water suddenly rise inside the jar.



What is happening?

A candle gets the oxygen it needs to burn from the air. It burns only as long as there is enough oxygen in the jar. Once the oxygen is used up, the flame goes out and water gushes in to take the oxygen's place. Candle wax is a hydrocarbon, a compound of carbon and hydrogen. When it burns, oxygen links with the carbon to form carbon dioxide gas and with hydrogen to form water.

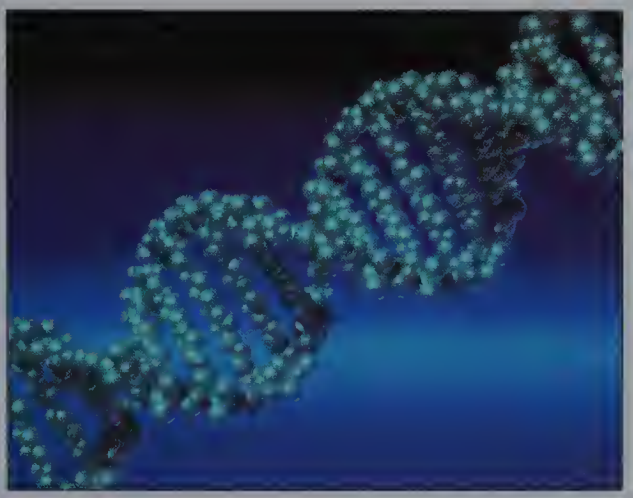
ACIDS AND BASES

All rain is slightly acidic because gases from the air, such as carbon dioxide, dissolve in raindrops as they fall. But air pollution can make the rain acidic enough to do real damage. This stone building has been damaged by acid rain.

In the real world

ACIDS IN THE BODY

The human body depends on a range of acids for many processes. Hydrochloric acid in the stomach helps dissolve food, making it easier to digest. Pyruvic acid plays a vital role in converting sugar to energy in each body cell. Amino acids are the building blocks of protein, the chemicals of which the body is made. Most remarkable of all is deoxyribonucleic acid, DNA. Molecules of DNA in each body cell provide the cell's full life instructions and carry the genetic code that provides the blueprint for a new human.



The amazing spiral molecule of the acid DNA carries all the instructions for life.

Anything that tastes a little sour is probably acid. Lemon juice is citric acid. Vinegar is acetic acid. Tea contains tannic acid. Weak acids like these are found in a huge range of foods, especially fruits, and are safe to eat.

Much stronger acids, such as concentrated sulfuric and nitric acid, are used in laboratories and industry. They are very dangerous chemicals that burn clothes or skin and may even dissolve metals.

All acids, weak and strong, contain hydrogen. When they are mixed with water, the hydrogen atoms lose their one electron. Electrons have a negative electrical charge, so atoms missing an electron are positively charged and are called positive "ions."

The chemical opposite of an acid is a base. Weak bases like baking powder taste bitter or may have a soapy feel. Strong bases like caustic soda are dangerous and corrosive.

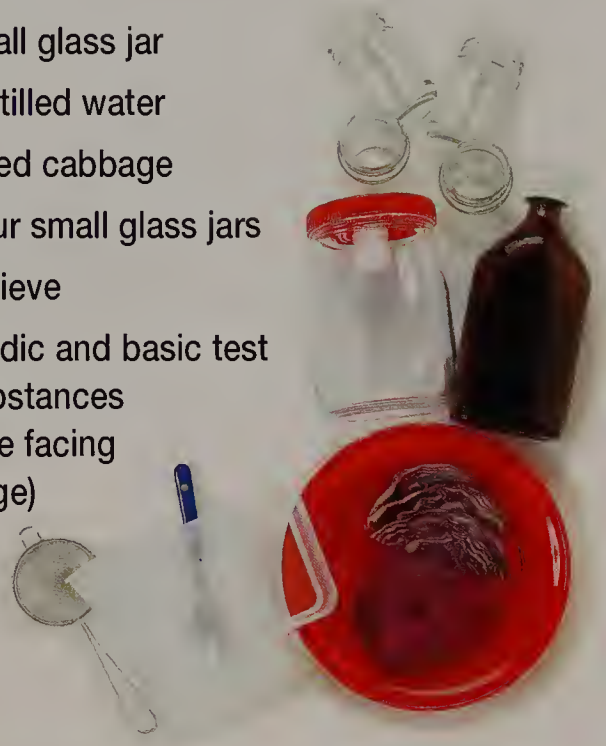
When a base reacts with an acid, it cancels out the acidity, neutralizing the acid. The acid and the base react together to produce water and a chemical called a salt. A wasp sting is basic and can be neutralized with an acid such as lemon juice. A bee or ant sting is acidic and can be neutralized with a base such as baking soda.

A base that dissolves in water is called an alkali. In contrast to acids, alkalis form negative ions when dissolved in water. These are not hydrogen ions, but ions of hydrogen and oxygen, called hydroxide ions.

ACID TESTS

You will need

- ✔ A pitcher
- ✔ A tall glass jar
- ✔ Distilled water
- ✔ A red cabbage
- ✔ Four small glass jars
- ✔ A sieve
- ✔ Acidic and basic test substances (see facing page)



1 Finely chop the cabbage and drop it into 1 pint (or 0.5 l) of distilled water. Ask an adult to boil the water for 10 minutes.

In focus

ACID SCALE

Some substances are more acidic than others, and some more basic. In 1909, Danish biochemist Soren Sorensen devised the pH scale for acidity. The letters pH stand for "potential Hydrogen," since the strength of an acid depends on how many hydrogen ions form. The strongest acids have a pH of 1, the strongest bases have a pH of 14. A pH of 7 is neutral, like pure water. Stomach acid has a pH of about 2, lemon juice has a pH of 3, rainwater about 5.5, human blood about 7.4, and ammonia cleaners about 11.

3 To see if a substance is acidic or basic, pour some cabbage liquid into each jar. Then add a little of the test substance.

2 Leave the deep-purple liquid to cool for half an hour, then strain it into the tall jar and dispose of the cabbage.

What is happening?

When red cabbage is boiled in pure, distilled water, it becomes an "acid-base indicator." This means it indicates how acidic or basic a substance is by changing color. It is turned red by an acid, changing through violet with a neutral substance, to blue with a weak base, green with a fairly strong base, and yellow with a very strong base. Red cabbage is just one of many natural indicators including geranium petals, blue grapes, and blackberries. Chemists still often use litmus paper. This is paper soaked in litmus—extracted from lichens—then dried. But most now use artificial indicators.

Basic substances such as ammonia cleaner and washing soda (sodium carbonate) turn the liquid green.

Tap water usually contains impurities that make it slightly alkaline. Like baking soda, it turns the liquid blue.

Distilled water has no impurities and is completely neutral, so it leaves the liquid unchanged in color.

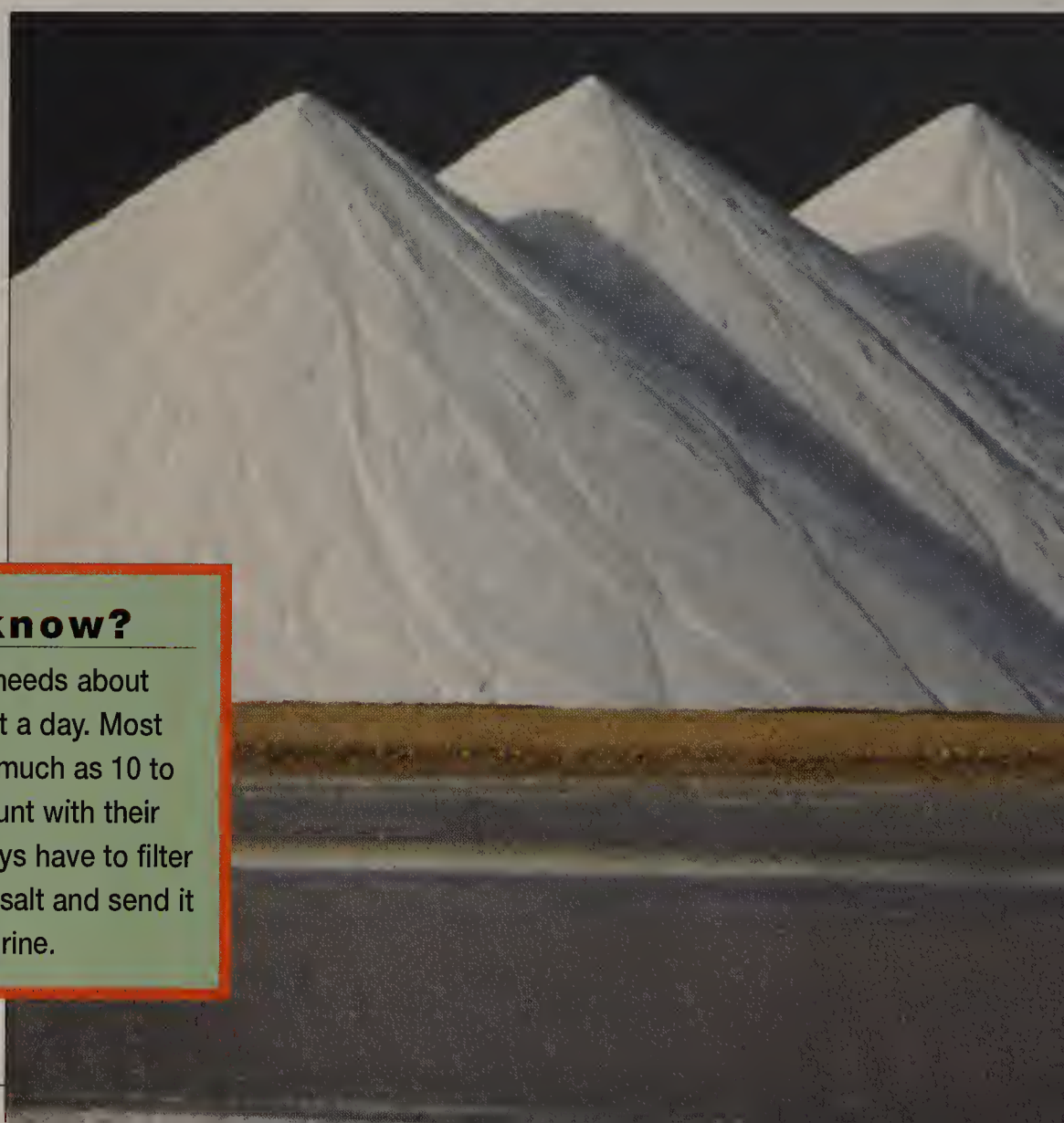
Lemon, vinegar, and cream of tartar powder are all acidic and turn the liquid bright red.

SALTS

Table salt is just one of many substances called salt. Bath salts are familiar around the home, but there are many other substances that chemists call salts. Many minerals, the natural chemicals rocks are made of, are different kinds of salt.

A salt is a compound that is made when an acid and a base react together. Table salt, for instance, is formed when the base sodium hydroxide neutralizes hydrochloric acid. Acids contain hydrogen and most bases contain metal and oxygen. When a salt forms, the acid's hydrogen swaps with the base's metal, leaving water (hydrogen and oxygen) and the salt (metal plus other elements).

All salts are solids made up of crystals. Crystals of table salt are white and cube-shaped. Some



Salt is often got out of rock underground by dissolving it with steam. Salty water is then pumped to the surface. The water evaporates, leaving huge piles of salt.

Did you know?

The human body needs about $\frac{1}{50}$ oz (0.5 g) of salt a day. Most people take in as much as 10 to 20 times this amount with their food, so the kidneys have to filter out the unwanted salt and send it from the body in urine.

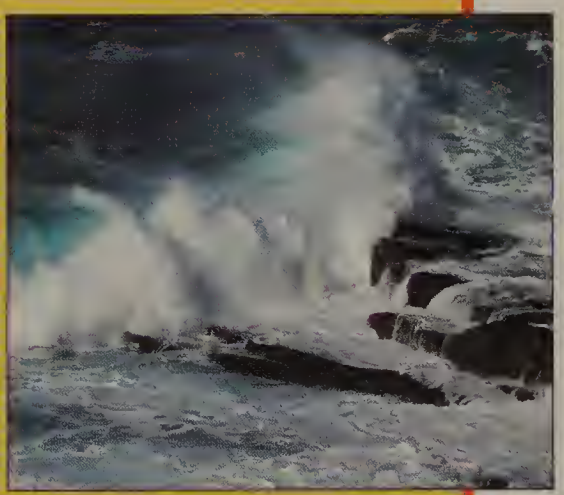
salts dissolve in water, like table salt; others won't. Tap water often has traces of dissolved salts, such as calcium carbonate, which make the water "hard." Hard water leaves a crust of limescale around taps and in kettles, and a lot of soap is needed to create a good lather. Some salts, however, make water softer, and some are used in the making of soap.

Salts are used in making a huge range of industrial and agricultural chemicals. The salt ammonium nitrate, for example, is used in fertilizers designed to add nitrogen to the soil. Natural mineral salts are also a source of metals such as sodium and potassium.

Plants and animals depend on various salts to stay alive. Table salt, for example, plays a crucial role in maintaining the body's water balance. The salts sodium chloride and potassium chloride are needed by nerves to send signals.

In focus

COMMON SALT



There is about 1 oz (100 g) of salt in every 2.5 pints (5 liters) of seawater. Most is sodium chloride, but there are also traces of magnesium, calcium, and potassium salts.

Table, or common, salt is the chemical compound sodium chloride, and is the most widely used mineral in the world. One expert calculated 16,000 different uses for it, besides in cooking. It is used in the food industry to preserve meat, fish, and vegetables, and also in making things such as margarine and butter. It is also used in making dyes, medicines, pottery, and leather, and it is spread on roads and pavements to keep them free of ice in winter. Most salt comes from thick layers of "rock salt" in the ground, but some is obtained by evaporating seawater.

CHEMICAL FORMULA

Using chemical equations, chemists can summarize and even predict what may happen when chemicals react.

Chemicals are named according to the elements they are made of. So aluminum oxide contains aluminum and oxygen. But some everyday chemicals have long names, like sodium hydrogencarbonate (baking soda). Other names are even longer. So chemists use shorthand symbols to identify the various chemical elements.

Often, an element's symbol is just its initial letter. The symbol for oxygen is O, carbon is C, and nitrogen is N. Where two chemicals begin with the same letter, a second small letter is added to distinguish them. So

hydrogen is H and helium is He. For chemists, symbols are not just shorthand; they can be combined to make a *formula* (plural *formulae*). By adding little numbers to the symbols, a formula can show how many atoms of each element make up a molecule of the chemical.

The symbol for hydrogen is H, but its formula is H_2 because hydrogen molecules have two atoms. With metals, carbon, and some gases, the symbol is the same as the formula, because molecules have a single atom. With nonmetals, such as sulfur (S), the molecules always have two or more atoms. The formula for sulfur is S_8.

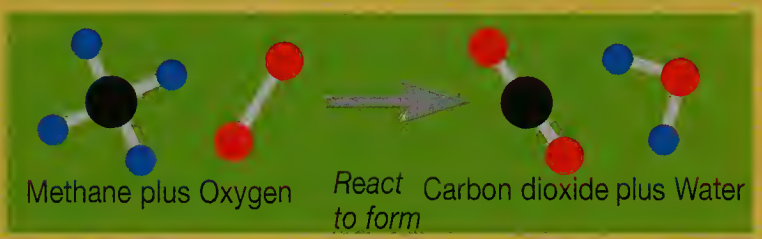
It works in the same way for compounds. A molecule of copper oxide is one atom of copper (Cu) plus one of oxygen (O), so the formula for copper oxide is CuO, the same as the symbols. But carbon dioxide molecules have one carbon (C) and two oxygen (O) atoms. So the formula for carbon dioxide is written CO_2.

Some chemical formulae show not only the atoms in a compound, but also the way they are linked together. The order of symbols in the formula for potassium nitrate is KNO_3. This shows the three oxygen atoms are linked not to the potassium (K) but to the nitrogen atom.

In focus

CHEMICAL EQUATIONS

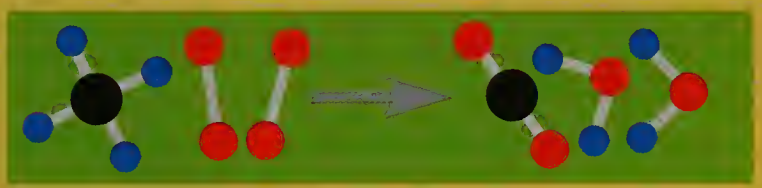
A chemical reaction can be described by writing an "equation." This shows the formulae for the reactants (original chemicals) and for the products. It is called an equation because all the atoms that were there before the reaction are still there at the end; they are simply rearranged to form different compounds. When methane (CH_4) reacts with oxygen (O_2), the methane's carbon joins oxygen to make carbon dioxide (CO_2); its hydrogen joins oxygen to form water (H_2O).



In formulae, this could be written:

$$CH_4 + O_2 \longrightarrow CO_2 + H_2O$$

This simply shows the chemicals involved, but is not an equation, because two hydrogen atoms seem to have been lost and an oxygen atom gained. In fact, they haven't been lost or gained at all. Experiments show that each molecule of methane reacts not with one molecule of oxygen but two, and the reaction creates not just one molecule of water but two.



So the equation should be written:

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$

The number of atoms before and after now matches to create a "balanced" equation. Whenever an equation does not balance with equal number of atoms either side, scientists try to work out how many extra molecules are needed to make it balance.

Experiments in Science

Science is about knowledge: it is concerned with knowing and trying to understand the world around us. The word comes from the Latin word, *scire*, to know.

In the early 17th century, the great English thinker Francis Bacon suggested that the best way to learn about the world was not simply to think about it, but to go out and look for yourself—to make observations and try things out. Ever since then, scientists have tried to approach their work with a mixture of observation and experiment. Scientists insist that an idea or theory must be tested by observation and experiment before it is widely accepted.

All the experiments in this book have been tried before, and the theories behind them are widely accepted. But that is no reason why you should accept them. Once you have done all the experiments in this book, you will know the ideas are true not because we have told you so, but because you have seen for yourself.

All too often in science there is an external factor interfering with the result which the scientist just has not thought of. Sometimes this can make the experiment seem to work when it has not, as well as making it fail. One scientist conducted lots of demonstrations to show that a clever horse called Hans could count things and tap out the answer with his hoof. The horse was indeed clever, but later it was found that rather than counting, he was getting clues from tiny unconscious movements of the scientist's eyebrows.

This is why it is very important when conducting experiments to be as rigorous as you possibly can. The more casual you are, the more "eyebrow factors" you will let in. There will always be some things that you can not control. But the more precise you are, the less these are likely to affect the outcome.

What went wrong?

However careful you are, your experiments may not work. If so, you should try to find out where you went wrong. Then repeat the experiment until you are absolutely sure you are doing everything right. Scientists learn as much, if not more, from experiments that go wrong as those that succeed. In 1929, Alexander Fleming discovered the first antibiotic drug, penicillin, when he noticed that a bacteria culture he was growing for an experiment had gone moldy—and that the mold seemed to kill the bacteria. A poor scientist would probably have thrown the moldy culture away. A good scientist is one who looks for alternative explanations for unexpected results.

Glossary

Acid: A compound that dissolves in water to produce hydrogen ions. Dilute acids taste sour. Strong acids are corrosive.

Alkali: A base that will dissolve in water, such as ammonia and the hydroxides of sodium, calcium, and potassium.

Atom: The smallest part of any chemical element. Anything smaller is no longer a chemical element. Each element has its own unique atom.

Base: The chemical opposite of an acid; a substance that neutralizes an acid by accepting hydrogen ions.

Bond: A link holding atoms together to make molecules.

Compound: A combination of two or more elements, joined chemically by bonds between atoms. Compounds have a double chemical name like sodium chloride.

Covalent bond: A chemical bond in which electrons are shared between atoms.

Electrons: The very tiny particles that circle the nucleus of an atom. They are negatively charged.

Elements: The very simplest chemical substances, each with a one word chemical name. There are just over 100 of them. They cannot be split into simpler substances by chemical reactions.

Equation: A way of writing down the chemicals involved in a reaction, showing the chemicals before and those after.

Formula: The symbol for a molecule of an element or compound, showing the number of atoms involved.

Ion: An atom that has either gained or lost (negatively charged) electrons and so become electrically charged.

Ionic bond: A bond between two or more ions, created as one atom donates an electron to another atom and becomes negatively charged. They are joined by mutual electrical attraction.

Mixture: A combination of substances in which there are no bonds between chemicals, so they can be separated physically.

Molecule: The smallest part of any element or compound which can normally exist alone.

Neutron: One of two kinds of particle in the nucleus of an atom. It carries no electrical charge, so is neutral.

Nucleus: The central cluster of protons and neutrons in an atom.

Oxidation: A reaction such as rusting or burning in which a chemical gains oxygen or loses hydrogen, or an atom or ion loses electrons.

Proton: One of two kinds of particle in the nucleus of an atom. It carries a positive electrical charge that balances the negative charge of an electron.

Reaction: When chemicals meet and change each other to form new chemicals.

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